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A METHOD OF REDUCING INTERFERENCE BETWEEN USERS AND USE
OF THE METHOD IN A RADIO ACCESS NETWORK

The present invention relates to a method of reducing interference between users and to use of the method in a radio access network. The preferred field of the invention is that of radio access networks using millimeter or sub-millimeter frequencies, referred to in the literature as local multipoint distribution systems (LMDS), for example. In LMDS networks, a base transceiver station uses a sectorial antenna and the antenna of the terminal of a user is a directional antenna pointed towards the base transceiver station serving a cell in which the terminal is located. The antenna of the base transceiver station need not be a sectorial antenna, however. The above systems are described in the article "Broadband radio access to home and businesses: MMDS and LMDS" by Hikmet SARI, published in the journal Computer Networks, Vol.31, by Elsevier Science Holland in 1999, pages 379 to 393.

The above networks provide an alternative to existing cable networks (copper wire pairs, coaxial cables or optical fibers), which have performance limitations or unacceptable infrastructure costs. The object of the invention is to solve interference problems which occur in the above networks.

In multipoint radio access networks, the base transceiver station antenna can be an omnidirectional antenna or a sectorial antenna. In the case of a sectorial antenna, a cell of the network comprises a plurality of sectors. Each sector conventionally uses a different frequency to the other sectors of the same cell (each sector can use a subset of frequencies and the subsets used in different sectors can be disjoint). The object of the principle adopted for allocating frequencies between adjoining cells is to minimize potential interference generated within the cellular network.

Figure 1 shows an example of a rectangular LMDS network with 90° sectors. Four frequencies or subsets of frequencies 1, 2, 3 and 4 are used in this type of cellular network, in which each cell is square and has a base transceiver station at its center. The base transceiver stations are represented by circles. Each cell is divided into four sectors corresponding to the four sectorial antennas of the base transceiver station. The continuous lines in Figure 1 are the boundaries between the sectors of the same cell. The dashed lines are the boundaries between the cells. Fixed user terminals are represented by dots. For example, the dots A, B and C represent terminals located in the same sector of the same cell.

One of the cells is shaded in the diagram. Each of the four sectors in a cell is labeled by a digit which indicates the frequency or the set of frequencies assigned to it. It can be seen that all the base transceiver stations use the same frequencies but that the frequencies are assigned to the various cells of the network in such a way that there is no interference between adjacent cells.

Other cellular network geometries can be defined, using sectorial antennas with different angular subdivisions, for example: 120°, 60°, or 45°. In all cases, operation of the network entails using a plurality of frequencies for each cell and generates interference between users of the system.

The carrier to interference (C/I) ratio is a function of the position of the user. The worst case scenario corresponds to points at the ends of the horizontal, vertical and diagonal lines of the cells for each base transceiver station. An antenna associated with the terminals located at these points is directed not only in the direction of its own base transceiver station but also in the direction of base transceiver stations on the same horizontal (or vertical or diagonal)

line. Given the way the frequencies are assigned, there is interference with a base transceiver station immediately following an adjacent base transceiver station along the horizontal (or vertical or diagonal) line. However, there is no interference with the adjacent base transceiver station.

Unfortunately, the ratio between the respective path lengths carrying a payload signal and an interference signal is small. For example, for the sector 1 of the base transceiver station in the top left-hand part of Figure 1, the three points A, B and C are the three least favorable points. If the distance between two adjoining base transceiver stations is denoted 2D, users at points B and C at the edge of the cell (and therefore at a distance D from their base transceiver station) with their terminal pointed towards their base transceiver station interfere with the base transceiver station at a distance 5D ($D+2D+2D$). The terminal B shown in Figure 2 is at the limit of the cell, on a horizontal straight line segment joining the base transceiver stations of the network. Of course, the same schematic could be applied at point C, on a vertical line joining the base transceiver stations. In the diagonal case (at point A), a factor $\sqrt{2}$ is applied to all the distances and the end result is the same.

Assuming that all the base transceiver stations transmit at the same power, the carrier/interference ratio is $C/I = 10\log(5^2)$, i.e. 14 dB. This description corresponds to a time division multiple access (TDMA) system having four frequency channels to cover the whole of a geographical area. If there are only two channels available, the C/I ratio associated with the least favorable points is then $C/I = 10\log(3^2)$, i.e. 9.5 dB. This can readily be shown by replacing 4 with 2 and 3 with 1 in Figures 1 and 2. It is then clear that in this case there is interference between adjacent cells.

The frequency allocation architecture chosen is

decisive in this regard. An operator is allocated a frequency band, which is by definition limited, in a given frequency range. This band has to carry uplink calls and downlink calls for each sector, allowing for
5 the fact that the base transceiver station transmits omnidirectionally, or at least sectorially, and the terminals transmit directionally. Considerations of equipment economy in the base transceiver stations lead to the choice of omnidirectional transmission for a base transceiver station.

10 INSA2/ An object of the invention is to remedy the above drawbacks and to provide an access technique in which such interference is no longer a problem. Although the invention is directed to solving problems encountered on
15 the downlink, there is nothing to prevent it being used also for the uplink. The invention therefore teaches, for the downlink at least, using a CDMA spread spectrum coding method employing the same frequency in all sectors. With CDMA spread spectrum coding, transmitted
20 +1 and -1 binary symbols are coded by multiplying them by a sequence of +1 and -1 coding bits, the sequence comprising $2N$ bits. The result of such multiplication is a sequence of +1 and -1 binary signals referred to as chips, the sequence comprising $2N$ chips. The chips are
25 then used to modulate a carrier whose signal is radiated by the antenna of the base transceiver station. Because the time allocated for sending a symbol remains the same, other things being equal, the spectrum spreading factor resulting from this process is $2N$. With orthogonal
30 coding sequences, for example Walsh Hadamard (WH) sequences, the number of different sequences that can be used is $2N$. The number of users that can be accommodated simultaneously in this geographical situation is therefore $2N$ per cell if the radiation is omnidirectional
35 and if a sequence is associated with each user.

In the access networks with directional user antennas described above, one type of interference to be

countered is entirely geometrical. It primarily affects terminals receiving transmissions from base transceiver stations aligned with them. For example, a receiver at point B in Figure 2 receives transmissions from base transceiver stations BTS1 and BTS2 because it points towards the base transceiver station BTS1. Because all the base transceiver stations transmit the same carrier, an interference problem arises at point B. Because the base transceiver stations are not synchronized, the orthogonal coding by coding sequences $2Ni$ (the coding sequence $2Ni$ is allocated to the downlink call from BTS1 to B) in no way protects the receiver B from transmissions from stations BTS2 and BTS3.

In accordance with the invention, to transmit a message to the user B from the base transceiver station BTS1, each symbol is coded with a double WH sequence. The double sequence includes first and second single sequences. In the remainder of this description, the term "single" sequence of length $2N$, is used for a sequence that is useable in the conventional way with a spectrum spreading factor $2N$, and the term "double" sequence of length $4N$ (or "triple" sequence of length $6N$, or "quadruple" sequence of length $8N$, etc.), is used for a sequence that is suitable for use in the invention, likewise with a spectrum spreading factor $2N$. A solution of the above kind effectively solves the problem because the user B will receive the transmissions addressed to them from the base transceiver station BTS1 with a sequence $2Ni2Ni$. The sequence $2Ni2Ni$ is in this case a double sequence of length $4N$. Received chips coded with the expected double sequence $2Ni2Ni$ will be decoded at a level 3 dB greater than chips coded with a single $2Ni$ sequence. This improves the quality of the received payload signal by 3 dB. In some cases this is sufficient for the payload signal to be recognized. If necessary, a symbol can be coded for transmission by a triple sequence, a quadruple sequence or any multiple sequence.

This progressively improves the signal to noise ratio.

The invention therefore provides a method of transmitting CDMA messages between a base transceiver station and user terminals, wherein:

5 - symbols of messages to certain user terminals are coded with a coding sequence of $2N$ bits to produce sequences of $2N$ chips, and

- the chips are transmitted,
characterized in that:

10 - symbols of other messages to certain other user terminals are coded with a coding sequence of $k2N$ bits to produce sequences of $k2N$ chips, where k is an integer greater than 1.

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The invention will be better understood on reading the following description and examining the accompanying drawings. The drawings are provided only by way of non-limiting and illustrative example of the invention. In the figures:

20 Figure 1 shows a rectangular cellular network with 90° sectors and has already been commented on;

Figure 2 shows an interference scenario in the network shown in Figure 1 and has already been commented on;

25 Figure 3 shows the assignment in accordance with the invention of orthogonal CDMA coding sequences within a cell;

Figure 4 shows a preferred way to generate a CDMA coded signal;

30 Figure 5 shows interference on an uplink channel from a user to a base transceiver station;

Figure 6 shows interference on a downlink channel from a base transceiver station to a user;

Figure 7 shows areas subject to high interference (in the downlink direction) shaded; and

35 Figures 8a and 8b show different coding modes in accordance with the invention.

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The networks described above show the limitations of

TDMA cellular networks. For a network with four frequency bands (occupied band 4W), in the worse case scenario, the carrier to interference (C/I) ratio is 14 dB. For a network with two frequency bands (occupied band 2W) the C/I ratio is 9.5 dB. The invention proposes to use a different access technology to improve these limitations, for example to obtain a C/I ratio better than 9.5 dB for an occupied band 2W. To this end, in accordance with the invention, the same frequency can be used in all sectors by employing the CDMA technique. A variant of that technique is proposed which significantly increases the C/I ratio associated with the least favorable positions.

As previously, an example is described which concerns a cellular network whose geometry reproduces that shown in Figure 1, but in which the four carrier frequencies (or groups of frequencies) 1 to 4 are replaced with a common carrier frequency coded by disjoint subsets S_1 and S_2 of orthogonal decoding sequences (for example Walsh-Hadamard sequences) of length $2N$. Figure 3 shows this. If there are more than four sectors, for example six or eight sectors, disjoint subsets of orthogonal sequences are allocated to two adjacent sectors in the cell. The number $2N$ is adopted here to simplify comparing the carrier to interference ratio of the invention to that of the prior art. However, this is not obligatory. The number could even be odd, although it is preferably even for other reasons.

The subsets S_1 and S_2 are assigned to the four sectors of a cell as follows. Two sectors of a cell on a diagonal line are served by a common subset of sequences S_1 (or S_2). Two contiguous sectors, meaning sectors which are side-by-side but in two adjacent cells, are served by two identical subsets S_1 (or S_2) of sequences. To achieve symmetry, the number of sequences in each subset will be N . This is not obligatory, however. If necessary, the general sequence distribution plan could

be altered. This mode of assigning frequencies prevents interference between neighboring sectors in a cell because of the orthogonal relationship of any of the sequences in subsets S_1 and S_2 .

5 All the cells of the network and all the sectors of each cell preferably use the same frequency band, of bandwidth $2W$. The use of a spreading factor equal to $2N$ is permitted within that bandwidth. The number of users per sector is limited to N (i.e. the total number of
10 users per cell is $4N$) by assigning each user a particular sequence taken from one of the subsets S_1 or S_2 of N sequences.

The preferred characteristics of the cellular network are therefore as follows:

15	- spectral occupancy:	$2W$
	- spreading factor:	$2N$
	- number of sequences assigned to a sector:	N
	- two adjacent sectors use disjoint subsets of sequences, each of cardinal number:	N
20	- maximum number of users in each sector:	N

It remains to minimize the interference between users of adjoining cells. All the adjoining cells use the same frequency band, the orthogonal relationship is lost because the base transceiver stations are not synchronized, and a user in one cell interferes with all the users in the other cells. The interference is deterministic and non-uniform, however. One way to make it uniform that is known in the art uses additional coding employing different PN sequences in each cell.

30 Each user's signal is therefore first spread by a sequence of length $2N$ and is then multiplied by a sequence PN, also of length $2N$, without additional spectrum spreading. The chips from the Walsh-Hadamard coder are multiplied by the bits of the PN sequence.
35 This latter operation, which is shown in Figure 4, is intended to separate the signals of different cells. There is therefore no interference between users in the

same cell, because their respective codes are orthogonal. However, a given user interferes with users in all the other cells. There is a finite level of interference because the various PN sequences that can be used are not 5 mutually orthogonal.

On the uplink channel from a user terminal to a base transceiver station the base transceiver station receives interference from a small number of users in the fields of their sector whose antennas are oriented towards the 10 base transceiver station at the center of Figure 5, as shown diagrammatically in the shaded areas in Figure 5. The total level of interference is therefore low, and the same for all users.

In contrast to an uplink channel user, a downlink channel user experiences interference which depends on their position within a sector. Consider first the 15 situation of users at the points A, B and C in Figure 6. User A is at the limit of the sector, on a diagonal line passing through the base transceiver station. Their 20 antenna is pointed towards their base transceiver station, which is at a distance $\sqrt{2}D$. The antenna is also directed towards another base transceiver station at a distance $3\sqrt{2}D$. If the sector associated with the other base transceiver station comprises K users, then the C/I 25 ratio is given by the equation:

$$C/I = 10\log[(2N/K)3^2] \quad (1)$$

For a payload signal normalized to 1, the interference created by a single user is $1/2N \times 3^2$, where the terms 3^2 and $2N$ respectively express the ratio of the squares of the distances and the gain due to the PN sequences (the correlation coefficient of two carefully chosen PN sequences of length $2N$ is equal to $1/2N$). In the presence of K users, the C/I ratio is therefore expressed 30 by equation (1). It decreases with K. For $K = N$:

$$C/I = 10\log(2 \times 3^2) = 12.5 \text{ dB}$$

The antenna of the user is also pointed towards other base transceiver stations, also on the diagonal

line, at distances $(2M+1)\sqrt{2}D$, where $M > 1$, but the corresponding interference will not predominate because the distance is greater.

The user B is at the limit of the sector, on the horizontal line passing through the base transceiver station. The user C is also at the limit of the sector, on the vertical line passing through the base transceiver station. Their antenna is pointed towards their base transceiver station, which is at a distance D, and also towards another base transceiver station, at a distance $3 \times D$, and receives interference from two sectors of the cell centered around the other base transceiver station. If the two sectors respectively comprise K_1 and K_2 users, then the C/I ratio is given by the equation:

$$15 \quad C/I = 10 \log \left[\left(\frac{2N}{K_1 + K_2} \right) \times 3^2 \right]$$

For $K_1 = K_2 = N$, then $C/I = 10 \log (3^2) = 9.5$ dB.

Note that these C/I ratios of 12.5 dB and 9.5 dB are valid, within each sector, only in the vicinity of the point A, on the one hand, and in the vicinity of the point B or C, on the other hand. Outside the shaded areas (see Figure 7), the C/I ratio is much greater than the above values.

For example, a receiver at a point A' on the diagonal line half-way between the edge of the sector and the base transceiver station, i.e. at the limit of the shaded area, receives the signal from its base transceiver station much more strongly than an interfering signal from another base transceiver station. If $K = N$ the C/I ratio is then equal to:

$$35 \quad C/I = 10 \log \left[2 \times \left(\frac{D\sqrt{2}/2 + 2D\sqrt{2}}{D\sqrt{2}/2} \right)^2 \right] = 17 \text{ dB}$$

For the points B' or C' on the horizontal or vertical line halfway between the edge of the sector and

the base transceiver station, i.e. at the limit of the shaded area, if $K = N$ the C/I ratio is equal to:

$$5 \quad C/I = 10 \log \left[2 \times \left(\frac{D\sqrt{2}/2 + 2D\sqrt{2}}{D\sqrt{2}/2} \right)^2 \right] = 14 \text{ dB}$$

Consequently, in terms of the C/I ratio, it is possible to distinguish three separate areas within a given sector:

10 - an area of high interference, in the vicinity of the points B and C, where the C/I ratio has a minimum value of 9.5 dB, equal to the value obtained for a system of the same bandwidth $2W$ using the TDMA technique;

15 - an area of slightly less interference, in the vicinity of the point A, where the C/I ratio can drop to 12.5 dB; and

20 - finally, the remainder of the sector, where the C/I ratio will always be greater than 14 dB (and even greater than 17 dB between A' and the base transceiver station).

Because the users' antennas are directional, with an aperture angle of the order of 2° to 4° , the area with the lowest C/I ratio will in fact cover the smallest part of the sector, which opens up the possibility of improving the C/I ratios of the areas with lower C/I ratios, subject to a reasonable additional coding cost.

In accordance with the invention, various objectives can be set:

30 1st objective: to improve the C/I ratio of areas B and C (the worst provided for),

35 2nd objective: to improve much more the C/I ratio of areas B and C and in parallel to improve also (but more modestly) the C/I ratio of the area A (which otherwise would become the worst provided for).

The idea of the invention is to assign users at the most unfavorable geographical positions within a sector a coding method enabling them to benefit compared to other

users, in order to compensate their a priori handicap. To this effect, the delimitation of the areas A, B and C defined in Figure 5 or 7 merely serves to illustrate this differential treatment according to the user's 5 geographical position. The invention remains perfectly applicable to areas with different limits, for example an area B extending from the point B to a point either beyond or short of the point B' on the horizontal line joining B and the associated base transceiver station.

10 The C/I ratio is greater than 12.5 dB at all points outside areas B and C. In accordance with the invention, without modifying the duration of the chips, and therefore the spectrum occupancy, a coding sequence of double length 4N, or triple or quadruple length, instead of a single length 2N, is associated with downlink calls from a base transceiver station to the disadvantaged 15 users in areas B and C. This reduces by 3 dB for doubling or 4.8 dB for tripling or 6 dB for quadrupling, for these disadvantaged users, the interference caused by a signal transmitted by another adjacent base transceiver 20 station and intended for other users. In practice, Figures 8a and 8b show how each symbol to be transmitted to a disadvantaged user is preferably subjected to at least two successive codings by two single coding 25 sequences of length 2N to form a double sequence of length 4N, and that the coding operation produces symbols comprising 4N chips. The sequences of length 4N must be orthogonal to the sequences of length 2N of other users and must be mutually orthogonal. The bits of these 30 streams of 4N successive chips are then processed in a transmitter like the bits of the sequences of 2N chips.

35 The situation is therefore one in which ordinary users employ a single coding sequence of length 2N per symbol while disadvantaged users benefit from a double sequence of length 4N per symbol. If necessary, a triple or quadruple coding sequence could be allocated for coding the same symbol of messages to be transmitted for

these disadvantaged users. It is just as if redundancy were added by repeating the symbol for only some messages. The messages for which such redundancy is added are messages to users singled out geographically, known to be disadvantaged from the communication point of view, and for whom quality can be improved by singling out the coding sequences assigned to them and doubling (tripling, etc.) the coding of the symbols of their messages by those sequences.

This halves (divides by three, four, etc.) the information bit rate (the duration of the chips remains exactly the same with the same spreading factor, so as not to increase spectrum occupancy), and to compensate for this it is preferable to associate two coding sequences of length $4N$ with the user in question to maintain a constant information bit rate (and therefore to offer that user the same service as other users). The quality improvement of 3 dB is therefore not net, since the number of sequences associated by the base transceiver station will increase.

Assuming that the number of users with double sequences of length $4N$ is equal to m per sector, the total number of single sequences is then $(N-m) + 2m = N+m$. $N-m$ users have a single sequence with a coding length of $2N$ and m users have a double sequence with a coding length of $2 \times 2N$. The real improvement in quality is:

$$G = 10 \log (2N / (N+m))$$

for $m = N/20$ $G = 2.8$ dB $\Rightarrow C/I_{(B \text{ or } C)} = 12.3$ dB

for $m = N/8$ $G = 2.5$ dB $\Rightarrow C/I_{(B \text{ or } C)} = 12$ dB

for $m = N/4$ $G = 2.0$ dB $\Rightarrow C/I_{(B \text{ or } C)} = 11.5$ dB

The net gain improves as the number of users requiring a double length sequence is reduced, and therefore as the size of areas B and C is reduced. The invention is perfectly applicable to fixed radio access systems, in which the user terminal antennas are highly directional.

There follows one example of the generation of

elongated sequences from a single length sequence, for $N = 4$ and $m = 1$:

1 1 1 11 111	s1	1111111111111111	- 2 sequences
		11111111-1-1-1-1-1-1-1	of length $4N=16$
			are associated
			with a user
1-11-11-11-1	s2		- 3 users have
11-1-111-1-1	s3		a sequence of
1-1-111-1-11	s4		length $2N=8$

Figures 8a and 8b show a preferred embodiment of the method according to the invention for a disadvantaged user. The user transmits a message including symbols a_1 , a_2 , a_3 , a_4 , etc. In each symbol time T_s , using conventional CDMA coding, a sequence of length $2N$ would normally be assigned, and in this example $2N$ equals 8. The symbol time T_s is therefore equal to $2N$ times the chip time T_c . In accordance with the invention, the symbol a_1 is assigned a coding sequence of length $4N$ (equal to 16 in this example). The coding sequence naturally last longer than the symbol time T_s of the symbol a_1 , because the number of chips transmitted is doubled without changing the frequency occupancy of the carrier. There are two possible solutions.

Either (Figure 8a) penalizing the user is acceptable and their usable bit rate is halved (or reduced by a factor of three or four, depending on the type of multiple sequence used). In this case, the actual symbol time becomes twice (three times, four times, etc.) the basic symbol time. In practice, to preserve an existing transmitter architecture, the simplest approach is to code a symbol a_1 to be transmitted for a given user twice in succession for each sequence $2N_i$. At the receiver, the simplest approach is to consider a double decoding length $4N$. In this case, the decoder uses a sequence of length $4N$, for example the first sequence indicated above for the user s_1 .

Or (Figure 8b), this penalty is not acceptable, in

which case two coding systems are used and two double coding sequences (each of length $4N$) are used simultaneously. For example, the two double sequences are the two provided above for the user s_1 . Thus, the 5 symbol a_1 is coded by the beginning of its double sequence, by a first subsystem. Then coding of the symbol a_2 is begun by a second subsystem using the beginning of its double sequence, while the symbol a_1 is still being coded by the first subsystem using the second 10 part of its double sequence. Each double sequence has a length $4N$ and a duration $4N$ times T_c . When the first subsystem has completed generating the chips relating to the symbol a_1 , it immediately begins to generate the chips relating to the symbol a_3 , under the same 15 conditions, although the symbol a_2 is still being coded by the second subsystem. And so on. If coding sequences of triple or quadruple length are chosen, three or four coding subsystems preferably operate simultaneously. Clearly by adopting this approach at least two symbols 20 are transmitted simultaneously, at least in part. In this case, an appropriate receiver would have to include two (three, four) decoder subsystems, used simultaneously to decode alternately symbols a_1, a_2, a_3, a_4 of a message transmitted to that user.

25 The first double sequence includes a repetition of the same single sequence (here with eight 1s) and the second double sequence includes a single sequence (the same as for the first double sequence) and another single sequence complementary to the first single sequence. In 30 this way the two double sequences are orthogonal to each other. In theory, it would be possible to constitute the double sequences from any single sequence, provided that the double sequences obtained were mutually orthogonal. However, because the double sequences are made up of 35 single sequences, mutually orthogonal single sequences whose number is limited (to $2N$), and therefore limits the number of users in the cell, must not be neutralized

unnecessarily.

Note that doubling, tripling or otherwise multiplying the subsystems is not a particularly high penalty in terms of hardware because coding and decoding are handled by processors already incorporated in the base transceiver station and the user terminals.

In Figure 8b, the symbols a_1 and a_2 could also be transmitted simultaneously on the two subsystems, followed by transmission of the symbols a_3 and a_4 , and so on.

To achieve greater improvement, by allocating users in high interference areas even longer sequences, for example sequences of length $8N$, and in order to comply with the constraint that the spectrum occupancy must not be increased, the number of sequences to be allocated to those users is also greater (4 for sequences of length $8N$). The following strategy could be used, for example:

- use sequences of length $8N$ for users in areas B and C: the gross improvement is 6 dB;
- use sequences of length $4N$ for users in area A: the gross improvement is 3 dB.

The following example illustrates this allocation:

- Total number of users: $N = 4$
- Number of users in area B or C: $m_1 = 1$
- Number of users in area A: $m_2 = 1$

Consider a user in area B or C with four sequences of length $8N$ generated from the sequence 11111111, which becomes, on the one hand:

11111111 11111111,

which becomes:

11111111 11111111 11111111 11111111, and

11111111 11111111 -1-1-1-1-1-1-1-1 -1-1-1-1-1-1-1-1,

and, on the other hand:

11111111 -1-1-1-1-1-1-1-1

which becomes:

11111111 -1-1-1-1-1-1-1-1 11111111 -1-1-1-1-1-1-1-1, and

11111111 -1-1-1-1-1-1-1-1 -1-1-1-1-1-1-1-1 11111111.

It can be seen that again a single sequence is used to produce all of the quadruple sequences. The single sequence is only combined with its complementary image. Thus a single sequence is preferably concatenated with one repetition of that single sequence or with a complementary single sequence.

Consider a user in area A with two sequences of length $4N$ generated from the sequence 1-11-11-11-1 which becomes, on the one hand:

10 1-11-11-11-1 1-11-11-11-1

and, on the other hand:

1-11-11-11-1 -11-11-11-11.

Consider two users with a sequence of length $2N$:

(a) 11-1-111-1-1, and

(b) 1-1-111-1-11.

For the general case, the net improvement can be evaluated by considering the total number of users (N), the number of users in area B or C (m_1) and the number of users in area A (m_2):

$$20 \quad \text{Total number of sequences: } T = (N - m_1 - m_2) + 4 \times m_1 + 2 \times m_2 \\ = N + 3 \times m_1 + 1 \times m_2$$

In area B or C, the net improvement is therefore:

$$25 \quad G_{\text{net}} = 10 \log \left(4 \times \frac{N}{N + 3m_1 + m_2} \right)$$

In the above equation:

(i) the factor 4 expresses the lengthening by a factor 4 of the sequences assigned to users in area B or area C;

30 (ii) the factor $N / (N + 3m_1 + m_2)$ expresses the ratio between the total number of single sequences assigned, allowing for the assigning of several single sequences to users in certain areas, and the number of single sequences that would be assigned if all users had only one sequence.

In area A, the net improvement is

$$35 \quad G_{\text{net}} = 10 \log \left(2 \times \frac{N}{N + 3m_1 + m_2} \right)$$

In the above equation:

(i) the factor 2 expresses the lengthening by a factor 2 of the single sequences assigned to users in area A;

5 (ii) the factor $N/(N+3m_1+m_2)$: see above.

This leads to the following numerical examples:

(a) $m_1 = N/8$ and $m_2 = N/8$

10 For area B or C, the C/I ratio with no lengthening of the sequences is 9.5 dB, the gross improvement due to lengthening the sequences is 6 dB, and the reduction of the improvement due to the increase in the number of sequences is 1.8 dB. The minimum C/I ratio in area B or C is 13.7 dB.

15 For area A, the C/I ratio in the absence of lengthening of the sequence is 12.5 dB, the gross improvement due to lengthening the sequences is 3 dB, and the reduction of the improvement due to the increase in the number of sequences is 1.8 dB. The minimum C/I ratio in area A is therefore 13.7 dB.

20 (b) $m_1 = N/20$ and $m_2 = N/20$

25 For area B or C, the C/I ratio with no lengthening of the sequences is 9.5 dB, the gross improvement due to lengthening the sequences is 6 dB, and the reduction of the improvement due to the increase in the number of sequences is 0.8 dB. The minimum C/I ratio in area B or C is 14.7 dB.

30 For area A, the C/I ratio in the absence of lengthening of the sequences is 12.5 dB, the gross improvement due to lengthening the sequences is 3 dB, and the reduction of the improvement due to the increase in the number of sequences is 0.8 dB. The minimum C/I ratio in area A is therefore 14.7 dB.

35 The ratios m/N can be evaluated by calculating the ratio between the areas of the shaded portions of a sector and of the sector itself (assuming that the user terminals are uniformly distributed within a sector). This ratio depends on the directionality of the users'

antennas. If users are distributed homogeneously within a sector, example (b) corresponds to the situation in which the combination (area B + area C) covers 5% of the area of a sector, the area A also covers 5% and the

5 "unshaded" area covers 90%.

The above considerations have been developed in the context of an ideal rectangular cellular network. They could equally be applied to other cellular network topologies, for example ones using a hexagonal pattern, 10 in which the base transceiver stations use 120° sectorial antennas. In a real system, installed in the field, the geometry of the cells is not as regular, as it must take into account the topography of the terrain and the 15 existence of buildings.

Interference can in some cases be partly reduced by 20 carefully choosing the location and the height of the base transceiver stations, within the limits of the possibilities offered by the terrain and buildings.

In contrast, the user terminals are in practice too 25 numerous to benefit from these engineering techniques. Also, their installation site is fundamentally determined by the residence of the user, and not by engineering parameters. Unlike the base transceiver stations, their installation cannot call on teams with expertise in site engineering techniques.

It is impossible in practice to minimize 30 interference in a really significant manner by using conventional engineering techniques.

Consequently, the method described above is of great 35 benefit: it is very simple to use in a fixed service system, because it is sufficient to allocate the lengthened sequences to the user stations whose geographical location corresponds to the high interference areas. It is also possible, by deducing an interference map from the nature of the terrain and buildings, to predict the level of interference that a user at a given location will experience and therefore to

assign them the type of sequence matching their situation *a priori*, even in the case of a real network. Digital models of the real terrain have already been established for France, for example, and can be used for this type of 5 calculation.

The system can also be used if the user stations are transportable, subject to the provision of a location device associated with the stations, for example.

10 The detection conditions can be determined empirically and the user stations can be provided with a switching device for selecting either a mode with redundancy or a normal mode.